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(54) Pressure sensing spark plug

(57) A strain gauge 10a is rigidly secured, e.g. by gluing or laser welding, to the outer surface of a mild steel spark plug body 6 which surrounds an insulator (4, Fig.1). The gauge 10a may be mounted in a recess 16 machined in the body 6 and formed of a mild steel base 18 coated with a ceramic insulating layer 20 and a piezoresistive layer 20 with palladium/silver terminals 24. The layers 20, 20 may be deposited by ink jet printing of material in a polymeric binder which is dried or fired.

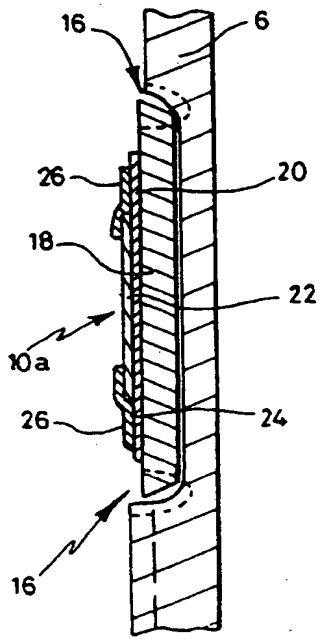

Fig. 5

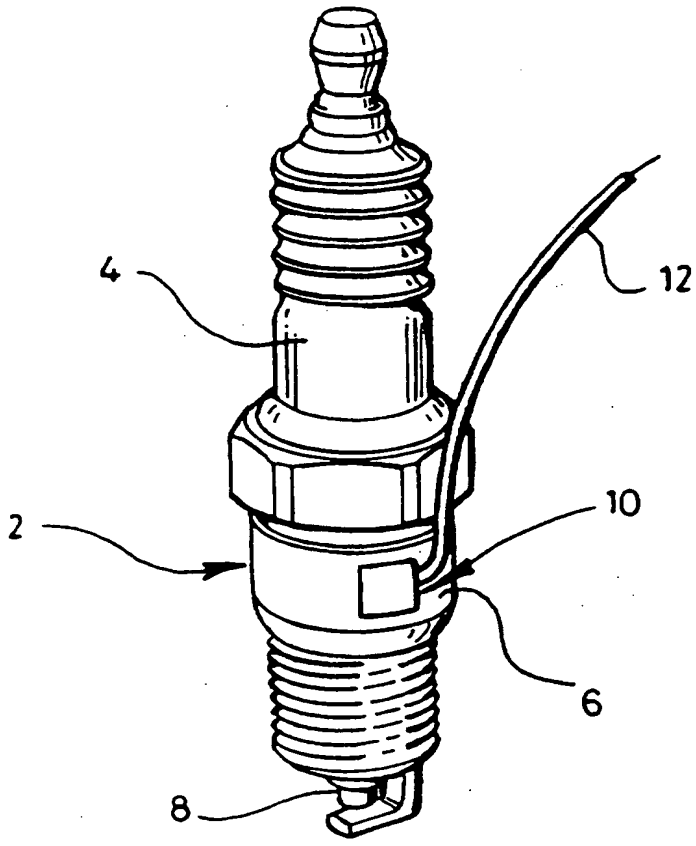

Fig. 1

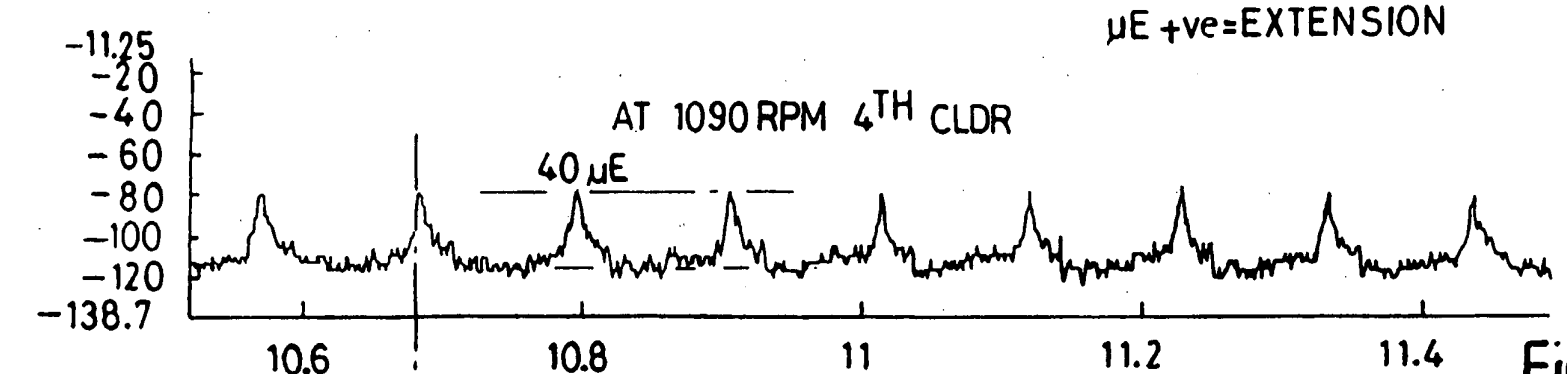
μE +ve=EXTENSION
-11.25
-20
-40
-60
-80
-100
-120
-138.7
AT 1090 RPM 4TH CLDR
40 μE
10.6
10.8
11
11.2
11.4

Fig. 2

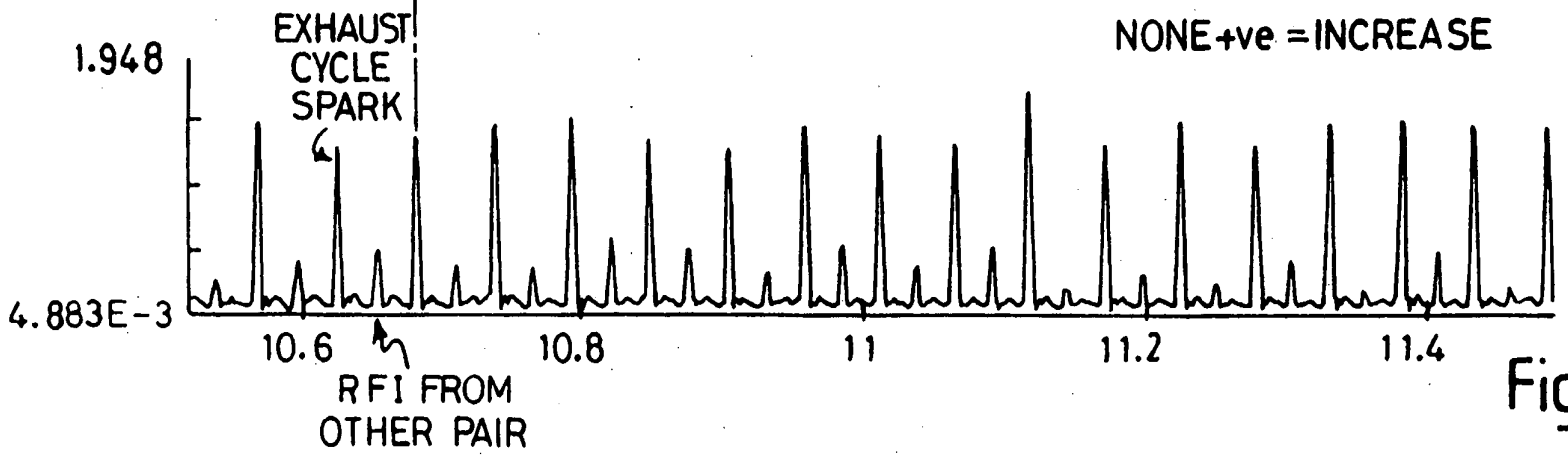
NONE+ve = INCREASE
1.948
4.883E-3
EXHAUST CYCLE SPARK
10.6
10.8
11
11.2
11.4
RFI FROM OTHER PAIR

Fig. 3

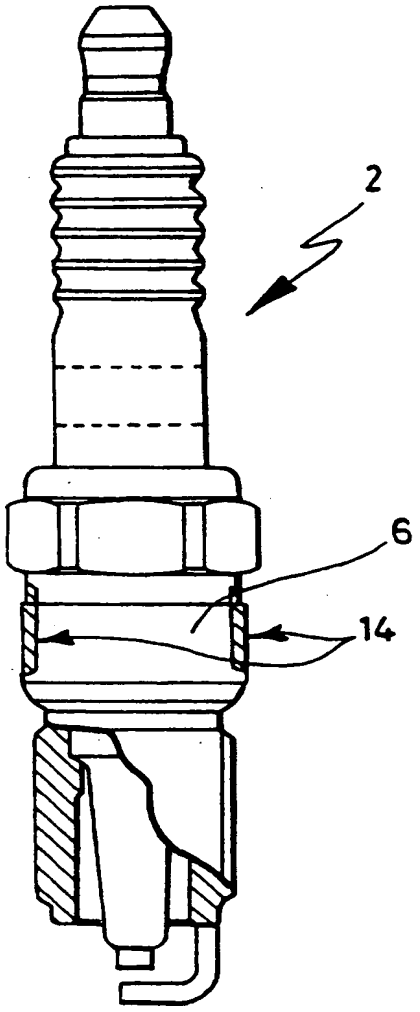

Fig. 4

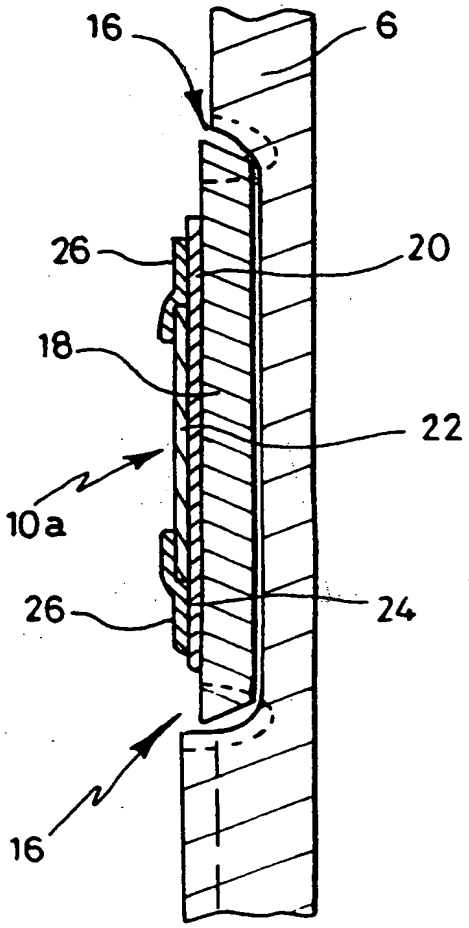

Fig. 5

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A PRESSURE SENSING SPARK PLUG

The present invention relates to a pressure sensing spark plug for use in an internal combustion engine, and particularly in an engine of motor vehicle.

It is known to mount a pressure sensor in a spark plug for measurement of instantaneous pressure in an engine combustion chamber. Such pressure measurements can be used in the control of engine timing and the detection of knock.

It has been proposed in European Patent Application numbers 0 581 067 and 0 609 787, to manufacture a spark plug with a built-in ring-shaped pressure sensor for use in engine management. A ring of piezoelectric material is held under compression inside the metal shell of the plug. A lead wire passes through a hole in the metal shell to output electrical signals. A problem with such spark plugs is that they require many more parts than a conventional spark plug, and the pressure sensor cannot readily be retro-fitted to a conventional spark plug.

According to the present invention there is provided a spark plug including an insulator through which is disposed a centre electrode, and an outer metal shell which is secured to the insulator, characterised in that a strain sensitive device is rigidly secured to the outer surface of the metal shell.

By rigidly securing a strain sensitive device to the outer surface of the metal shell, the strain (increase in length) of the shell can be measured. When the spark plug is mounted in a combustion chamber of an engine, the amount of strain on the shell is related to the pressure

in the combustion chamber. A signal from the strain sensitive device may therefore be used to provide an indication of cylinder pressure for use in an engine management system.

The location of the strain sensitive device on the outer surface of the metal shell may also reduce radio frequency interference (RFI) from the high tension leads. It is preferred that the metal shell be made of steel, because steel is particularly effective at shielding electrical and magnetic components of RFI.

The signal from the strain sensitive device may provide an absolute measurement of strain or cylinder pressure if the device is calibrated. However it is envisaged that the device may be used to determine when peak cylinder pressure occurs and when knock occurs, without the need for calibration. The spark plug may therefore be used in the control of ignition timing to obtain mean best torque (MBT), or to detect misfiring.

Any suitable strain sensitive device may be used. However it is advantageous to maximise the strain gauge signal output to increase signal to noise ratio. This can be achieved by:

- reducing the thickness of the shell around the circumference, and instrumenting the strain in this reduced section. The shell thickness should be reduced to a minimum, without causing fracture of the shell in service. The signal output can be increased typically by a factor of two or three by doing this.

- replacing the conventional foil gauge, which has gauge factor 2, with a thick film piezoresistor, with

gauge factor approximately 10. This can increase the signal output by a further five times.

In another embodiment the strain sensitive device comprises a piezoelectric material which produces a voltage signal related to the strain in the shell.

The strain sensitive device may be secured to the shell by any suitable means, for example by gluing or laser welding.

The strain sensitive device could also be formed on the metal shell, for example by spraying onto the shell a solution or dispersion of a suitable resistive material in a polymeric binder.

One or more wires may be attached to the device by known techniques such as ultrasonic welding or soldering. The wires may be attached either before or after securing the device to the shell. To aid attachment of wires, the ends of the resistor may be coated with an adhesion promoter, for example a palladium/silver alloy.

The strain sensitive device may be secured to the metal shell during the manufacture of the shell or the spark plug. Alternatively the spark plug may be manufactured by rigidly securing a suitable strain resistant device to the metal shell of a conventional spark plug. Preferably this manufacture includes the additional step of machining a recess in the metal shell, in which the strain resistant device is to be secured.

The invention will now be further described, by way of example, with reference to the following drawing in which:

Figure 1 is a perspective view of a spark plug in accordance with the present invention;

Figure 2 is a graph of strain against time for the spark plug of Figure 1 in an engine running at 1090 rpm;

Figure 3 is a graph of ignition timing for the spark plug of Figure 1;

Figure 4 is a part sectional view through a spark plug, indicating where the shell thickness may be reduced for use in the present invention; and

Figure 5 is a sectional view through part of the shell of a spark plug in accordance with the invention.

The spark plug 2 (Motorcraft AGRF 22) shown in Figure 1 comprises an insulator 4 through which is disposed a centre electrode 8, and an outer metal shell 6 which is secured to the insulator 4.

A conventional foil strain gauge 10 (Micro Measurements EA-06-062AQ-350) is rigidly secured to the outer surface of the metal shell 6 by means of a strain gauge adhesive (MBond 200). A mineral-insulated take-off lead 12 is attached to the strain gauge 10, for connection to an engine management system (not shown).

An Ono Sokki inductive pick up sensor was attached to the spark plug high tension lead, and this sensor was used to mark the point at which the spark plug was fired. An analogue engine speed tachometer was used to indicate the engine's rotational speed *via* a pulsed output from the low

tension side of the ignition coil. The strain signal and point of ignition signal were amplified in a signal conditioning unit (Data Acquisition Limited, model DA 1428).

All signals were then recorded in an analogue format on VHS tape using a TEAC XR 50 tape recorder. The VHS data tape was digitised and imported into a Portax computer system. The sampling rate was set to 1 kHz. The data were reviewed using n'Soft software.

When the spark plug 2 is mounted in an engine cylinder, combustion pressure in the cylinder exerts an outward force on the spark plug insulator 4 which causes the metal shell 6 to strain (increase its length) by a small amount. This strain is detected as a change in resistance by the strain gauge 10, which therefore provides an indicator of cylinder pressure.

The information from the pressure signal can be used to control ignition timing to obtain mean best torque (MBT) and in the detection of misfiring.

When installed in all the cylinders of an engine, the spark plugs 2, with strain gauges 10, may therefore be used to improve engine performance, fuel economy, and engine life. Optimum engine management will also allow reduction of exhaust emissions.

Figure 2 shows the measured value of strain against time in seconds for the spark plug 2 in a cylinder of a 1.3 HCS engine running at 1090 rpm. The measurements are correlated with the ignition timing graph shown in Figure 2, and the engine speed graph of Figure 3.

It can be seen that peak pressure is generated soon after the point of ignition in the cylinder. Figure 2 also shows the generation of a spark during each exhaust cycle, and RFI from sparking in another pair of spark plugs (seen as smaller peaks between the larger peaks).

These results show that cylinder combustion pressure causes measurable strain in the spark plug shell.

The absolute strain (pressure) value need not be known to relate the peak pressure measurements to the ignition timing. However absolute values may be determined by calibrating the strain gauge at appropriate temperatures if desired. Such a calibrated strain gauge may be used experimentally to analyse the performance of different engines without the need drill holes in the engine cylinder.

Signal to noise ratio can be improved using a reduced thickness shell and higher output strain sensor as previously stated. Figures 4 and 5 show the modification of an AGRF 22 spark plug to a spark plug in accordance with the present invention. Shell strain will be increased by 2.7 times by thinning of the shell, and the use of a thick film piezoresistor will produce around five times the output of the previously used foil strain gauge.

Metal is removed from the hatched area 14 in the shell 6 of the spark plug 2. The shell 6 is made of cold formed mild steel. A strain gauge 10a is welded to the shell 6 in the recess formed by the removal of metal at 14, in the areas generally denoted by dashed lines 16.

The strain gauge 10 comprises a slip 18 of dimensions 6 mm x 4 mm coated with a ceramic thick film insulating layer

20, and a thick film piezoresistor layer 22. The slip 18 is made from mild steel (BS1449 Pt1 CR1). Terminal pads 24, formed from a palladium/silver alloy, are located at each end of the piezoresistor layer 22. Take-off leads can be attached to the terminal pads 24 by soldering or ultrasonic welding at the points 26. Any suitable take-off leads may be used. For example the take-off leads may be mineral insulated, metal sheathed, or polyimide coated.

The assembly shown in Figure 5 may need to be coated with a protective layer to prevent or reduce corrosion or other environmental attack. Such a system is preferably durable for at least six years.

Installation of a strain gauge as described will cause little disruption to existing spark plug assembly lines, and the strain gauge could also be installed onto different makes of spark which are already assembled.

A spark plug in accordance with the invention could be made at lower cost by applying the insulating layer, thick film resistor, and optionally the terminal pads directly to the spark plug shell by ink jet printing or other suitable coating means. However such materials are polymer based, and will need to be carefully selected for durability under normal operating conditions in an engine.

The invention provides a spark plug which is simple to construct, which can be used to monitor pressure in an engine cylinder.

CLAIMS

1. A spark plug including an insulator through which is disposed a centre electrode, and an outer metal shell which is secured to the insulator, characterised in that a strain sensitive device is rigidly secured to the outer surface of the metal shell.

2. A spark plug as claimed in Claim 1, wherein the strain sensitive device is a resistive strain gauge.

3. A spark plug as claimed in Claim 1 or Claim 2, wherein the strain sensitive device is secured to the metal shell by welding.

4. A spark plug as claimed in any one of the preceding claims, wherein the strain sensitive device is secured to the metal shell by laser welding.

5. A spark plug as claimed in any one of the preceding claims, wherein the metal shell is provided with a recess in which the strain sensitive device is secured.

6. A method of manufacturing a spark plug as claimed in any one of the preceding claims, wherein the strain sensitive device is formed on the metal shell of the spark plug by a process which includes the steps of:

a) applying to the metal shell a solution or dispersion of an insulator in a polymeric binder;

b) drying or firing the solution or dispersion to form an insulating layer on the shell;

c) applying to the insulating layer a solution or dispersion of a piezoresistive material in a polymeric binder; and

d) drying or firing the solution or dispersion to form a piezoresistive layer on the insulating layer.

7. A method of manufacturing a spark plug as claimed in Claim 6, wherein at least one of the solutions or dispersions is applied by ink jet printing.

8. A method of manufacturing a spark plug as claimed in any one of claims 1 to 5, which method comprises rigidly securing a strain sensitive device to the outer surface of the metal shell of a conventional spark plug.

9. A method as claimed in Claim 8, further including the step of machining a recess in the metal shell in which the strain sensitive device is to be secured.

10. A method as claimed in Claim 8 or Claim 9, wherein the strain sensitive device is secured by laser welding.

11. A spark plug substantially as herein described with reference to and as shown in Figure 1 or Figure 5 of the drawing.

10

Patents Act 1977
Examiner's report to the Comptroller under Section 17
(The Search report)

Application number
GB 9517540.2

Relevant Technical Fields

(i) UK Cl (Ed.N) F1B G1N (NAFD3, NAGD3)

(ii) Int Cl (Ed.6) G01L 23/22

Search Examiner
R J DENNIS

Date of completion of Search
25 SEPTEMBER 1995

Databases (see below)
(i) UK Patent Office collections of GB, EP, WO and US patent specifications.

(ii) ONLINE: WPI; JAPIO

Documents considered relevant following a search in respect of Claims :-
1 TO 11

Categories of documents

X: Document indicating lack of novelty or of inventive step.

Y: Document indicating lack of inventive step if combined with one or more other documents of the same category.

A: Document indicating technological background and/or state of the art.

P: Document published on or after the declared priority date but before the filing date of the present application.

E: Patent document published on or after, but with priority date earlier than, the filing date of the present application.

&: Member of the same patent family; corresponding document.

Category	Identity of document and relevant passages		Relevant to claim(s)
A	GB 2001765 A	(LIST)	1
X	US 4169388	(BENDIX)	1, 5 and 8

Databases: The UK Patent Office database comprises classified collections of GB, EP, WO and US patent specifications as outlined periodically in the Official Journal (Patents). The on-line databases considered for search are also listed periodically in the Official Journal (Patents).